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This report summaries activities at the Workshop. Workshop sponsors were the Air Force Office of Scientific Research (AFOSR), the Army Research Office (ARO), and the National Science Foundation (NSF).

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A Summary Report of the 3rd Workshop on Structural Health Monitoring

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ABSTRACT

The 3rd International Workshop on Structural Health Monitoring was held at Stanford University, September 12-14, 2001, with about 130 participants. Major topics in the technical presentations and panel discussions were sensor and actuator development, sensor networking and embedding, damage identification and properties/integrity characterization and assessment, system integration, applications, and cost vs. benefit. All technical presentations at the workshop were published in the proceedings of the workshop; "Structural Health Monitoring: The Demands and Challenges," (CRC Press).

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I. INTRODUCTION

This report summaries activities at the "3rd International Workshop on Structural Health Monitoring" at Stanford University, Sept. 12-14, 2001. The objectives of the workshop were to review the progress of the current development in structural health monitoring technologies, identify key and emerging issues in research and development, and promote exchange and cross-fertilization across many disciplines and applications.

A committee was formed to organize the workshop. Distinguished individuals from industry, academe, and government were invited to deliver keynote lectures and presentations. Product and technology demonstrations were planned, as well as poster paper presentations. Panel discussions on key issues and concerns identified during the workshop were held each day. A proceedings of technical presentations was produced.

250 abstracts were submitted, and because of space limitations, only 130 were selected for oral and poster presentation.

Major topics of the workshop included:

Sensor and Actuator Development
Fiber optics, piezoelectrics, shape memory alloys, microelectronic sensors, new microsensors and micro-actuators.

Sensor Networking and Embedding
Distributed sensor network, sensor network optimization, sensor embedding technologies, local/global signal processors.

Damage Identification and Properties/Integrity Characterization and Assessment
New, innovative damage and corrosion detecting techniques and identification methods, real-time processing monitoring techniques, nonmechanical in-situ characterization,

modal and nonmodal analyses, neural network technologies, generic algorithms, inverse solvers.

System Integration
Manufacturing/processing, signal processing/data generation, wireless communication, hardware and software integration.

Applications

- Power/utility facilities: Power plants, overhead/underground facilities, remote transmission facilities, etc.
- Civil infrastructures: Bridges, highway systems, buildings, etc.
- Aircraft and missile structures: Helicopters, airplanes, engines, motor cases, etc.
- Space structures: Satellites, space stations, reusable launch vehicles, etc.
- Land/marine structures: Automobiles, submarines, ships, etc.

Cost/Benefit
Cost/benefit: In-depth evaluation of cost-benefit analysis of impact of structural heath monitoring systems on space and aircraft industry.

Unfortunately, the tragic event on September 11, 2001 occurred on workshop registration day. Nearly all of the US participants were unable to attend the workshop. Most people were enroute to the workshop, and, after the incident, their flights were either forced to return or diverted to other locations. Fortunately, over 110 people (300 people had pre-registered) had arrived early and were able to register on the 11th. Under the circumstances, it was decided to proceed with the workshop as scheduled.

II. DEMANDS OF SHM

Reliability, performance, and life cycle costs are real concerns for almost all in-service structures such as civil infrastructures, transportation systems, and medical devices. These concerns begin when structures are deployed and continue throughout their lifecycle. Since service time and environment can significantly impact a structure's physical condition while in service, these concerns become more and more severe as the service life increases.

Maintenance is needed in order to maintain the integrity and safety of the structures, resulting in increasing life cycle costs. Deploying a structure for service involves three major engineering disciplines: analysis and design, manufacture, and maintenance (Figure 1). A structure's reliability and performance are characterized in the analysis and design discipline with testing and analyses before manufacture. Data and analytical tools are generated from coupons and prototypes in "simulated" or "assumed" environments. The results of the analyses and design provide design guides for manufacture and service manuals for end users. To ensure that the structural reliability and performance is maintained, appropriate manufacturing techniques are developed and quality control is reinforced through fabrication, within the manufacturing discipline.

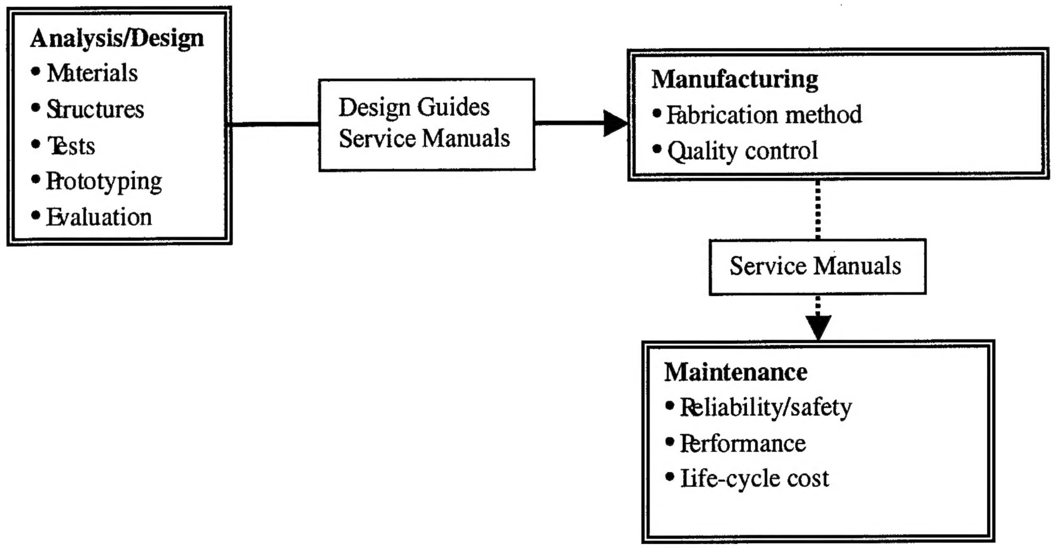

Figure 1 Typical of engineering design-to-service flow diagram for in-service structures.

A manufactured structure is placed in service following the third engineering discipline – maintenance, where the structures are maintained in accordance with service manuals. Due to uncertainties in actual conditions that structures experience in service, routine and frequent inspections are required. As service time increases, the degree of confidence in the structure's reliability and performance decays, and periodic inspection will increase. As the structure ages, confidence in reliability and performance declines, and costs associated with maintenance increase (Figure 2). Furthermore, to account for uncertainties in actual physical conditions and service environments, a structure is commonly over-designed or not utilized fully at optimal performance. This phenomenon of decaying confidence in structural reliability and under performance would remain fundamentally unchanged as long as the current design-to-service diagram is not altered, as shown in Figure 1.

In order to enhance reliability and improve performance, the state of a structure's physical condition and service environment, in real time, must be known. The structural health monitoring (SHM) technologies [1-3] under the framework of smart structures principles provide unique solutions to the problem. With smart sensing and intelligent diagnostics, structural conditions can be monitored and damage can be detected while the structures are in service. Optimal structural performance could be achieved while in operation because the actual structural conditions are known and the structures are readily adaptive to change. Residual life could be predicted and catastrophe could be prevented. These structures would be maintained only when needed, significantly reducing maintenance costs.

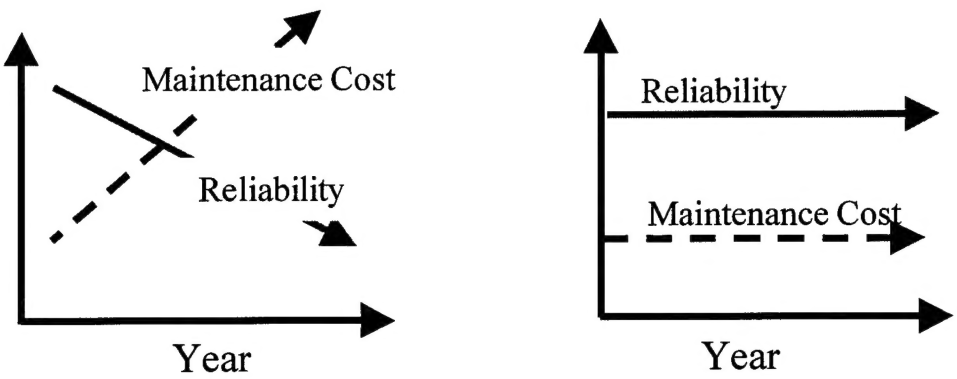

Figure 2. (Left) Structures without SHM system; (Right) Structures with SHM system.

Accordingly, structural health monitoring technologies could result in (see Figure 2):

- Ultra-reliable, extremely safe structures;
- Optimal in-service performance; and,
- Easy operation and minimal maintenance cost.

In order to integrate the structural health monitoring technology into structures, a fundamental change in the traditional engineering design-to-service diagram is needed (Figure 3). Within the analysis and design discipline, sensor/actuator technology and techniques for integration of sensor systems with structures must be considered. New and innovative design guides for integrated sensor/structures must be developed within the manufacturing discipline. In addition, a new engineering discipline in signal processing, informatics, and diagnostics must be introduced and included in the traditional design-to-service diagram for integrated structures with a structural health monitoring system (Figure 3).

Within the new engineering discipline, signal processing/diagnostic algorithms are required to process and interpret signals obtained from the sensors built into the structures and information techniques are needed to transmit data from sensors to processing units with wired or wireless communication. The analytical tools and test data that were generated from the analysis and design should be utilized and incorporated with the algorithms to develop software for interpretation of structural condition when real sensor data are collected from in-service structures.

Based on the new design-to-service diagram, the data and analytical tools generated from the analysis and design could be utilized for maintaining the structures, in service, with intelligent software and real sensor measurements. However, in the traditional design-service practice, this data and analyses would not be used after the structures have designed.

It is important to point out that the structural health monitoring technology could be applied to both existing and new structures. The new design-to-service diagram could be applied to both cases. For new structures, sensor systems could be embedded inside the structures during manufacturing; however, for existing structures, they may have to be mounted or coated on the surfaces. Accordingly, manufacturing techniques for both cases can be quite different.

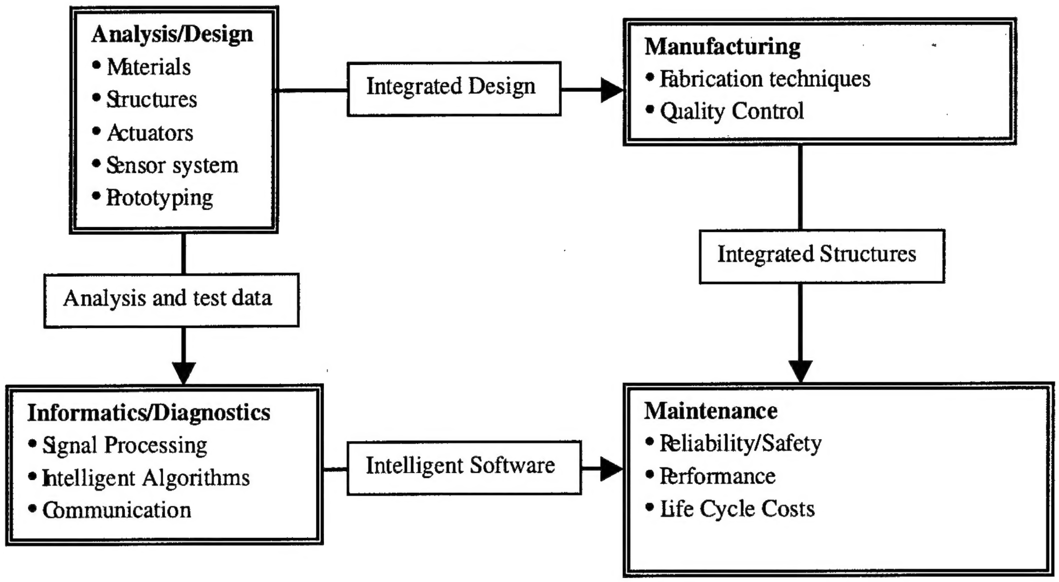

Figure 3. A new structural design-to-service diagram with a structural health monitoring system.

Once developed, the SHM technologies could be applied broadly to civil infrastructures such as highways, bridges, buildings, tunnels, and railroads, aeronautical and space transportation systems such as aircraft, ground vehicles and surface ships, and biomedical devices such as implants, surgical tools and instruments.

III. MAJOR CHALLENGES

Although smart structures techniques have demonstrated promising results recently, the following major technical barriers remain:

1. Specialty sensors: Multi-functional specialty sensors are needed for a variety of structural applications. These materials and devices must be durable, reliable, sustainable and compatible with host structures.
2. Sensor system: Sensor networking with and without wireless communication and local processing power is important for implementation and installation.
3. System integration/manufacturing: New design technologies and manufacturing methods are needed for producing integrated SHM structure systems. Integrating

sensors, electronics, and communications within structures posts significant challenges to design and manufacturing.

4. Intelligence algorithms/software: The ability of structures to monitor health, detect failure, mitigate damage, and predict residual life depends strongly upon how intelligent software is at interpreting sensor signals and relating the measurements to critical physical parameters. Currently, such a predictive capability is lacking, significantly inhibiting the progress of structural health monitoring technologies.

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